(19) **United States**
(12) **Patent Application Publication** (10) **Pub. No.: US 2005/0150460 A1**
Sarigiannis et al. (43) **Pub. Date: Jul. 14, 2005**

(54) **INSITU POST ATOMIC LAYER DEPOSITION DESTRUCTION OF ACTIVE SPECIES**

(75) Inventors: **Demetrius Sarigiannis**, Boise, ID (US); **Shuang Meng**, Boise, ID (US); **Garo J. Derderian**, Boise, ID (US)

Correspondence Address:
FISH & NEAVE IP GROUP
ROPES & GRAY LLP
1251 AVENUE OF THE AMERICAS FL C3
NEW YORK, NY 10020-1105 (US)

(73) Assignee: **Micron Technology, Inc.**

(21) Appl. No.: **11/009,425**

(22) Filed: **Dec. 10, 2004**

Related U.S. Application Data

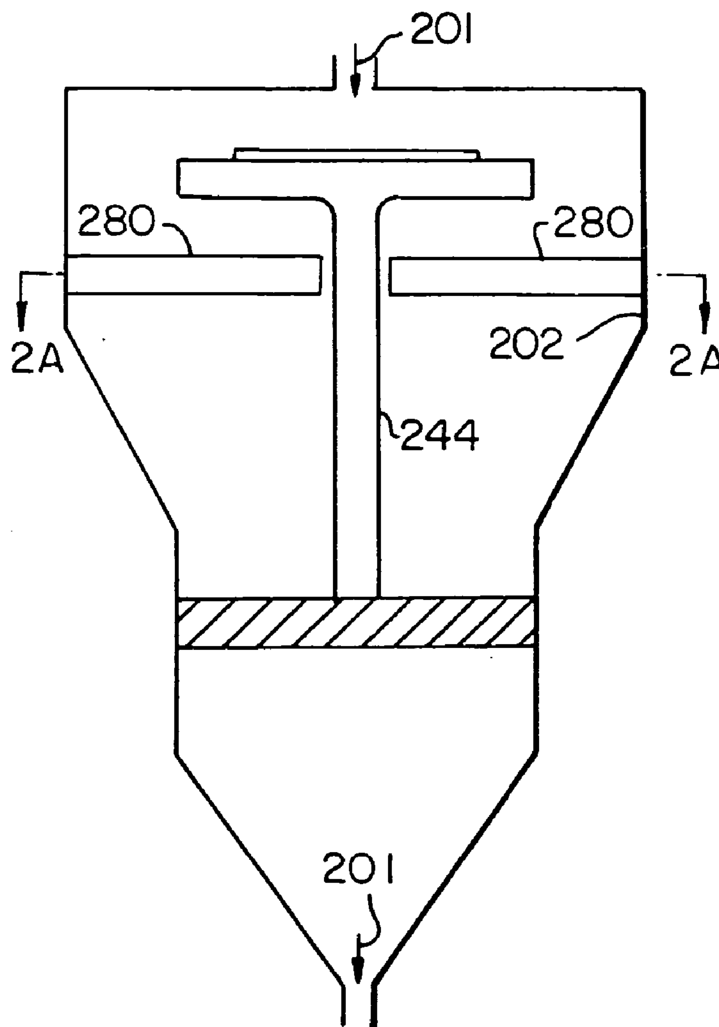
(63) Continuation of application No. 10/356,981, filed on Jan. 30, 2003, now Pat. No. 6,844,260.

Publication Classification

(51) **Int. Cl.**^{7} **C23C 16/00**
(52) **U.S. Cl.** **118/725**

(57) **ABSTRACT**

Systems and methods for insitu post atomic layer deposition (ALD) destruction of active species are provided. ALD processes deposit multiple atomic layers on a substrate. Pre-cursor gases typically enter a reactor and react with the substrate resulting in a monolayer of atoms. After the remaining gas is purged from the reactor, a second pre-cursor gas enters the reactor and the process is repeated. The active species of some pre-cursor gases do not readily purge from the reactor, thus increasing purge time and decreasing throughput. A high-temperature surface placed in the reactor downstream from the substrate substantially destroys the active species insitu. Substantially destroying the active species allows the reactor to be readily purged, increasing throughput.



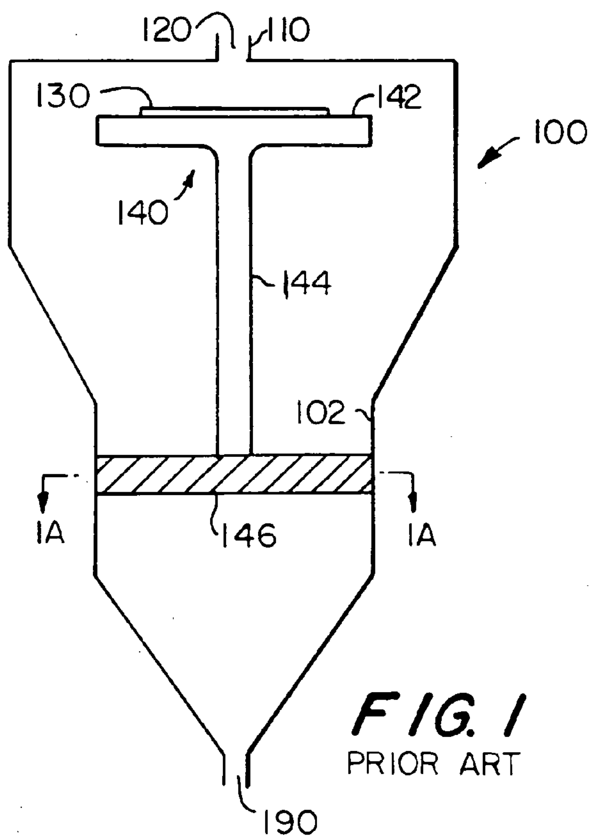


FIG. 1
PRIOR ART

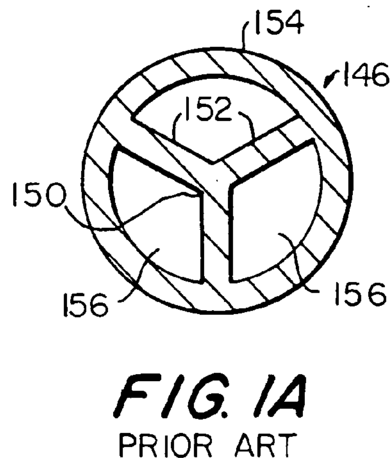


FIG. 1A
PRIOR ART

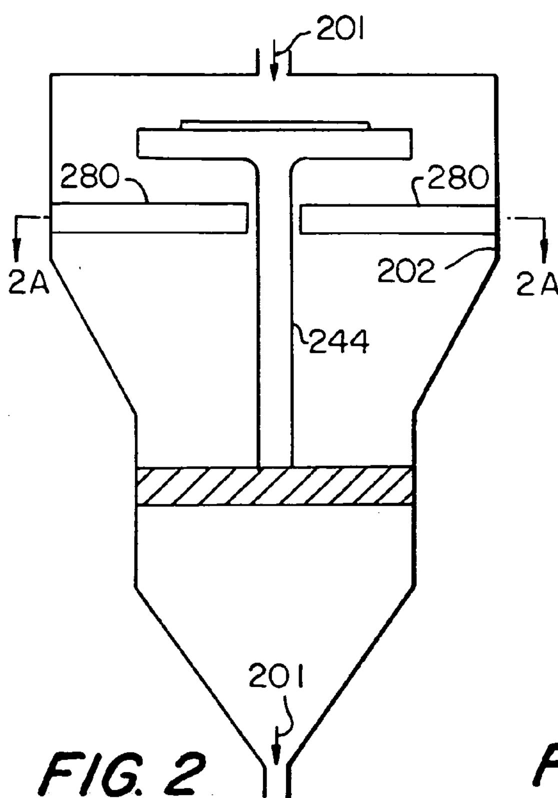


FIG. 2

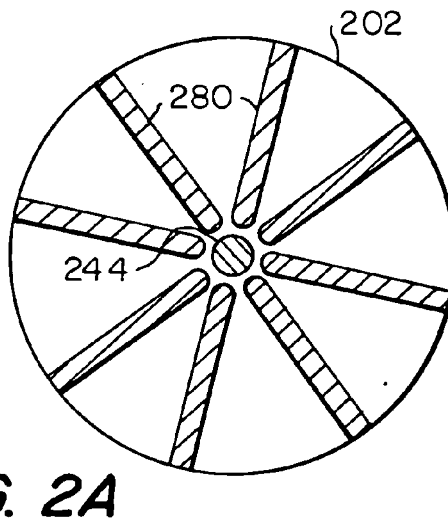


FIG. 2A

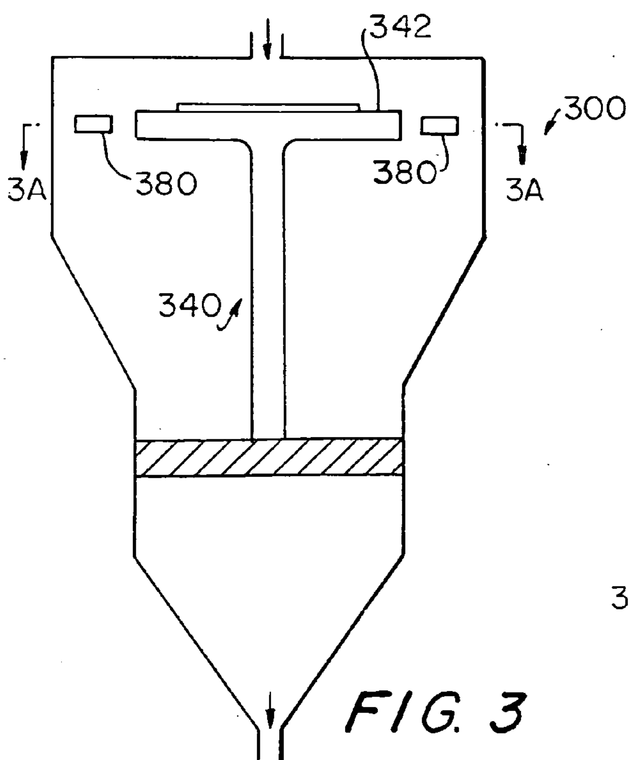


FIG. 3

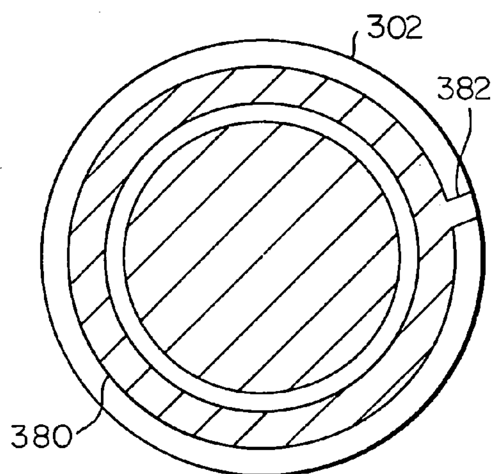


FIG. 3A

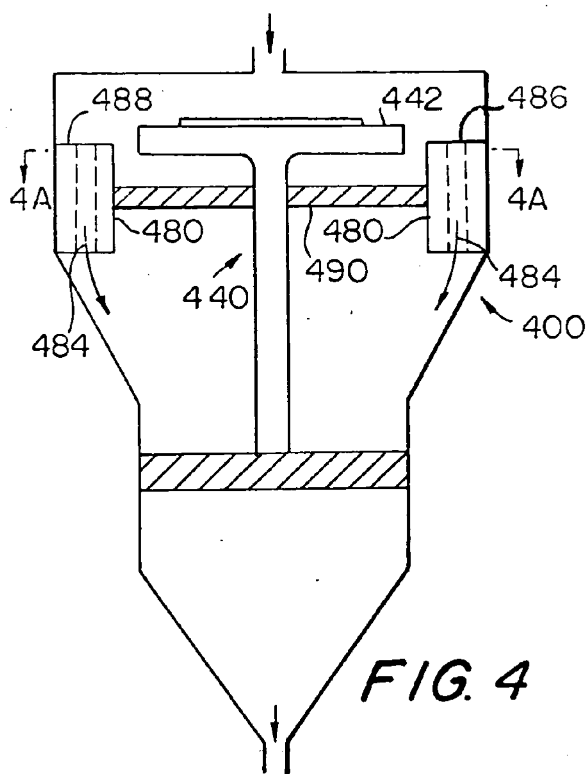


FIG. 4

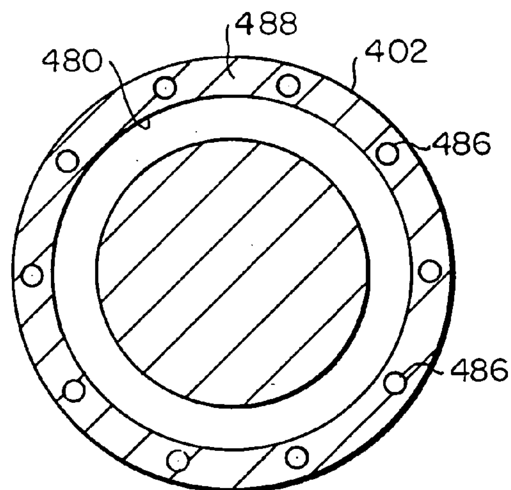


FIG. 4A

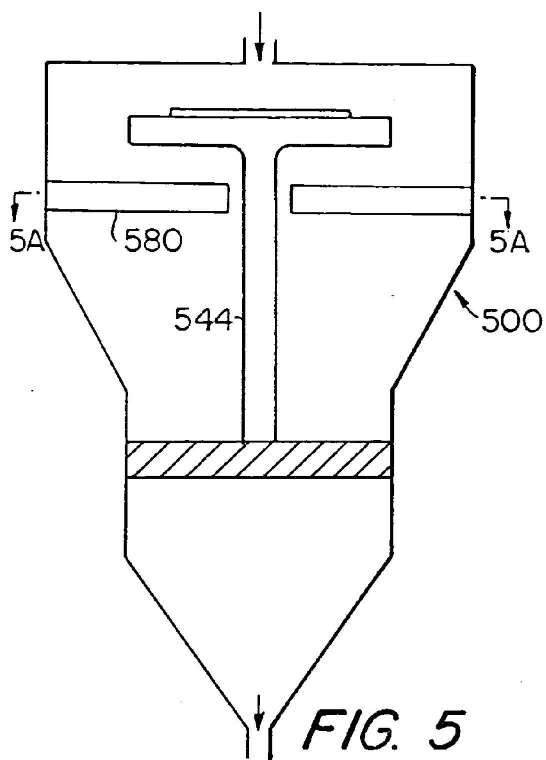


FIG. 5

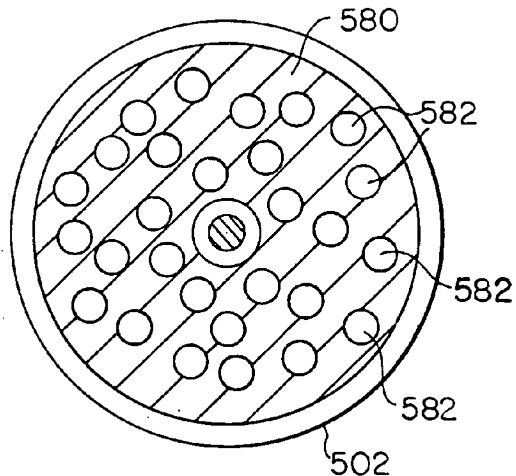


FIG. 5A

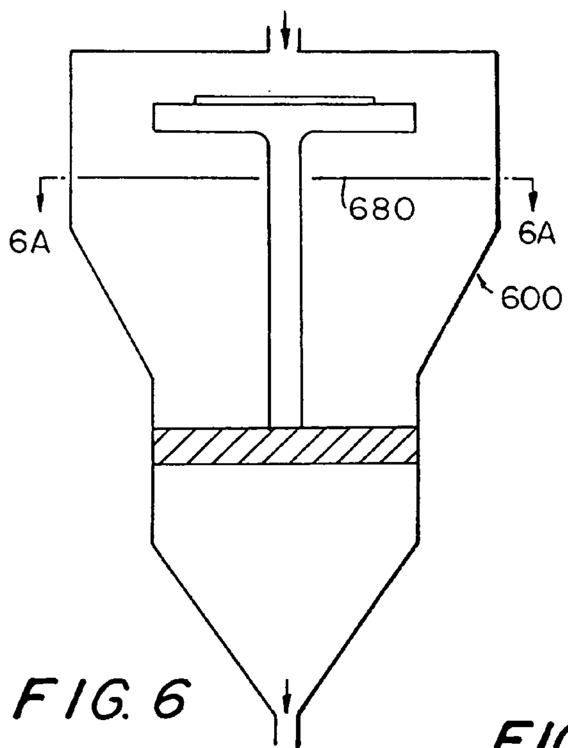


FIG. 6

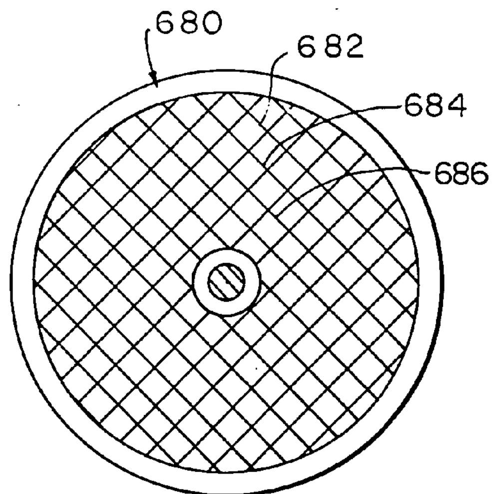


FIG. 6A

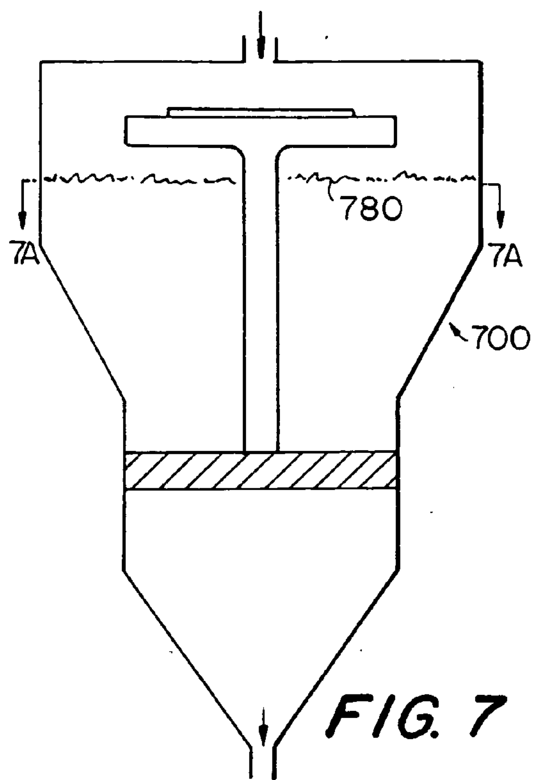


FIG. 7

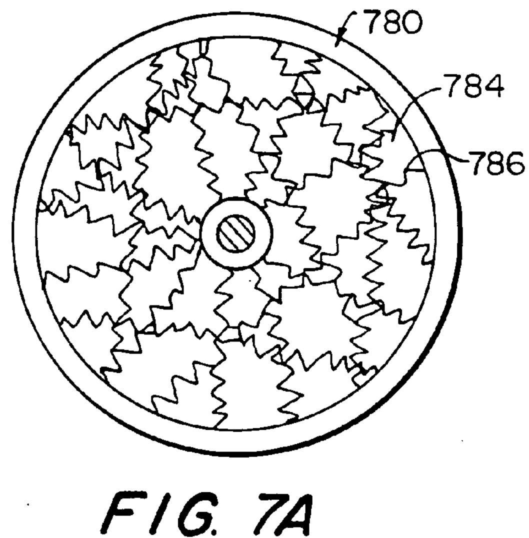


FIG. 7A

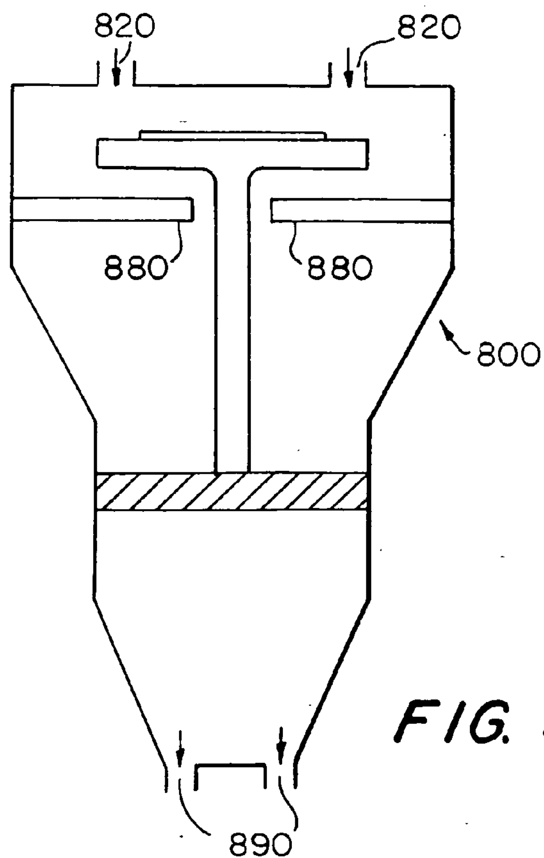


FIG. 8

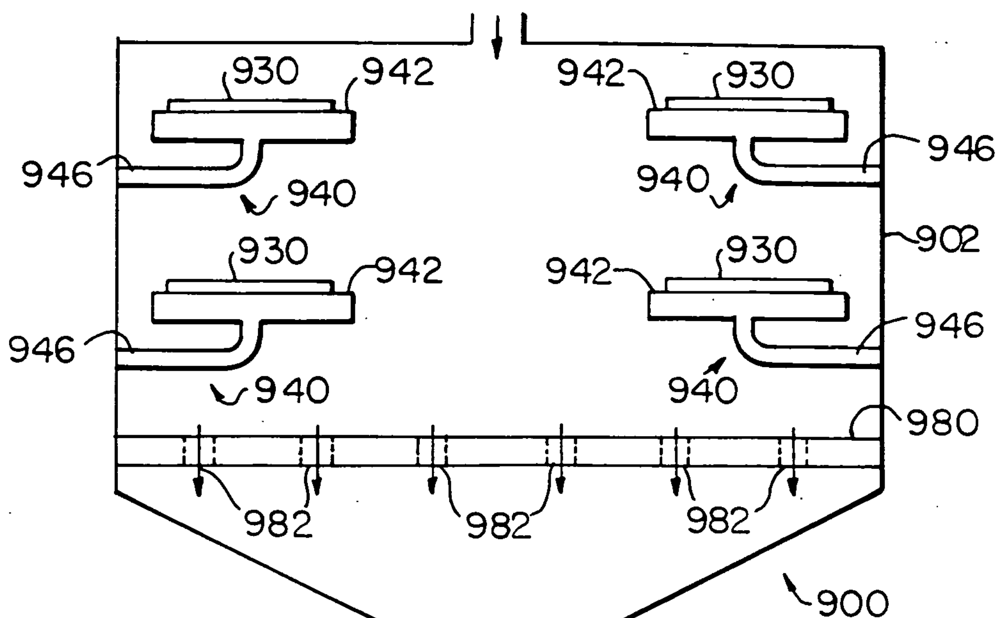


FIG. 9

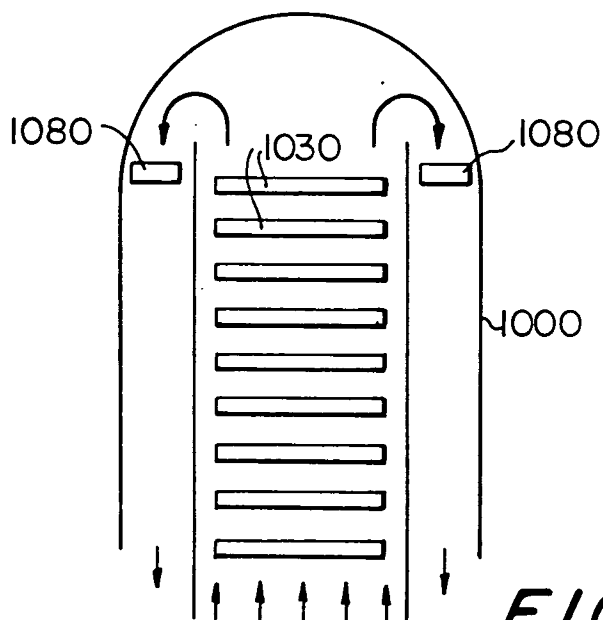


FIG. 10

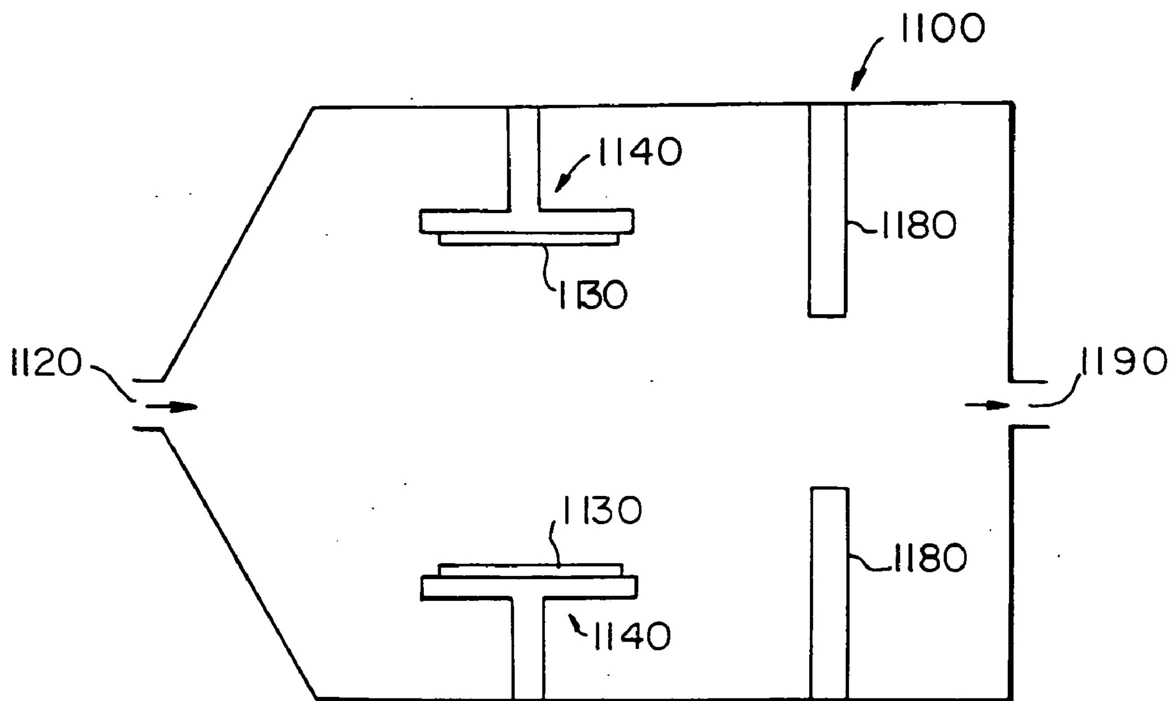


FIG. 11

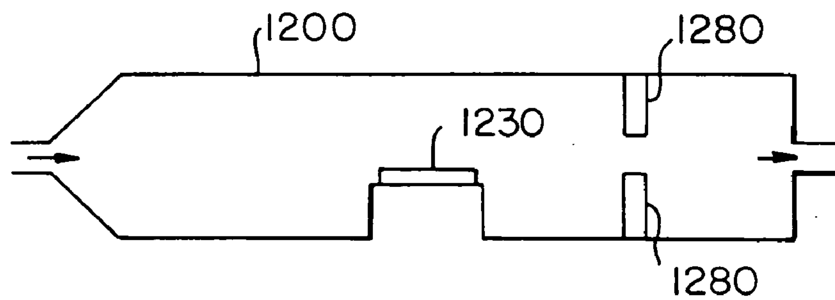


FIG. 12

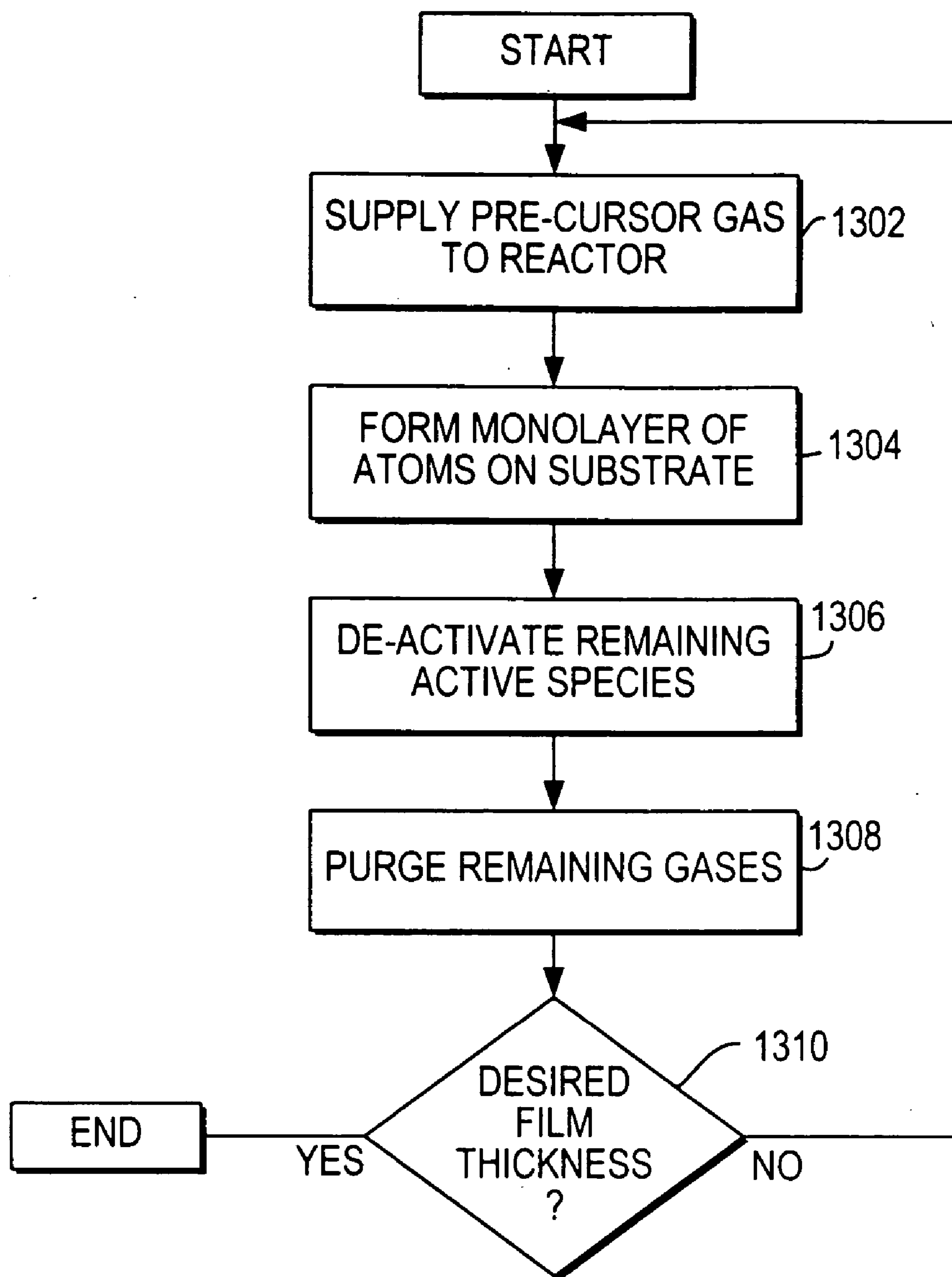


FIG.13

INSITU POST ATOMIC LAYER DEPOSITION DESTRUCTION OF ACTIVE SPECIES

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This is a division of U.S. patent application Ser. No. 10/356,981 filed Jan. 30, 2003, which is hereby incorporated by reference in its entirety.

BACKGROUND OF THE INVENTION

[0002] This invention relates to systems and methods that destroy active species of pre-cursor gases used in atomic layer deposition (ALD). More particularly, this invention relates to systems and methods that destroy active species of pre-cursor gases inside the reactor in which the ALD occurs.

[0003] ALD is a process in which atoms are deposited on a substrate, monolayer at a time, to grow a multi-layered thin film. In typical ALD processes, a first pre-cursor gas enters a reactor in which a substrate is placed. The first pre-cursor gas saturates the surface of the substrate forming a first monolayer. The reactor is then typically purged with an inert gas. Purging is required to prevent parasitic chemical vapor deposition (CVD) reactions from occurring between the first pre-cursor gas and a second pre-cursor gas that enters the chamber after purging. If most of the pre-cursor gas is not purged from the chamber, these reactions can form particles that will either ruin the thin film being grown, result in an undesired CVD-type deposition, or both. Problems associated with CVD-type deposition include poor step coverage and poor uniformity.

[0004] After the first pre-cursor gas is purged, a second pre-cursor gas enters the reactor and reacts with the adsorbed monolayer or partial monolayer (i.e., the first monolayer) to form a monolayer of the desired film. The reactor is again purged with an inert gas. This process is repeated until the thin film is grown to a desired thickness.

[0005] In some ALD reactions, one of the pre-cursors may include an active species. An active species is a molecule that is not in its most stable state. Active species will readily react to either accept or donate electrons in a reaction (e.g., O_3, O^* or N^* (where * denotes an excited state with excess energy)). Because most active species readily decay or recombine into a more stable state as temperature increases, they have a relatively short half-life in an ALD chamber operating at temperatures in excess of 400° C. However, in some cases, it may be advantageous to grow a film via ALD at lower temperatures such as 200° C. In this situation, the half-life of the active species is increased, and for a given purge time, there is a higher initial concentration of active species present to be purged from the reactor. This directly reduces the throughput of the reactor.

[0006] Variables that can affect the half-life of active species of gases include temperature and pressure. As temperature and pressure increase, the half-life of the active species decreases because of simple kinetics. Destruction of the active species is necessary because of their high reactivity. For example, an active species such as ozone can irritate the eyes and lungs, and so should be completely converted into O_2 before being discharged to the atmosphere. ALD processes that require the use of an active species typically run at temperatures high enough to destroy (e.g., consume or decompose) most of the active species before they leave the chamber. This reduces the concentration level of the active species significantly.

[0007] However, current experience with ALD processes indicates that it may be advantageous to operate at temperatures lower than the high temperatures of many known ALD processes. For example, many of the metal-organic precursors that may be used in the ALD of hafnium (Hf) oxide decompose at temperatures higher than 200° C. Therefore, in order to obtain a film with acceptable properties (e.g., step coverage, low carbon content) the reactor must be operated at a temperature close to or lower than 200° C. When ozone is used as an oxidizer in this process, these lower temperatures are not sufficient to decompose all of the ozone before it leaves the reactor.

[0008] For example, in the ALD of hafnium oxide, if ozone is supplied to a reactor and the chamber is running at 400° C., a certain percentage of the ozone, X, will be consumed by the reaction with the Hf pre-cursor and another percentage, Y, will be consumed by kinetic recombination of the O_3 and O^* to form O_2. This kinetic recombination reaction is driven by temperature. The overall percentage of ozone remaining in the chamber will be Z. However, if the chamber is running at 200° C., the percentage of ozone that recombines will be far less than Y. Thus, the amount remaining to be purged will be greater than Z. This requires a longer purge time.

[0009] In view of the foregoing, it would be desirable to decrease the purge time of active species of pre-cursor gases from reactors used in ALD to improve throughput.

SUMMARY OF THE INVENTION

[0010] It is an object of this invention to decrease the purge time of active species of pre-cursor gases from reactors used in ALD to improve throughput.

[0011] Some active species of pre-cursor gases that do not readily decay at typical ALD reaction temperatures are known to readily decay at temperatures higher than the ALD reaction temperatures. For example, when aluminum oxide is deposited using trimethylaluminum (TMA) and ozone (ozone includes O_3, O_2, and O^*), the active species of the ozone (i.e., O_3 and O^*) do not readily decay at the typical reaction temperature of about 300° C. That is, a large percentage of the active species remains active. In other words, a large concentration of the active species remains in the reactor. This hinders the throughput of the reactor. However, at higher temperatures (e.g., at temperatures equal to or greater than 400° C.) the active species of the ozone readily break down.

[0012] There are three ways to decrease the concentration of an active species in the reactor: i) consume more O_3 in the surface reaction to grow film (in ALD this is limited because only one monolayer is grown at a time); ii) increase the temperature to destroy more active species via a kinetic recombination reaction; iii) purge for a longer time. The addition of a high temperature surface beyond the wafer but before the outlet will destroy more active species. This will drop the concentration of the active species to one that can be reduced more readily with a shorter purge time.

[0013] In accordance with this invention, a high-temperature surface is placed inside the reactor to significantly speed

the decay of the active species and thus increase the throughput of the reactor. The high-temperature surface preferably has a high surface area. The high-temperature surface is preferably a metal, other material, or combination thereof that can be heated to a temperature high enough to induce the rapid decay of the active species of a pre-cursor gas used in ALD. The high-temperature surface may also include a material that catalyzes the active species to further increase the rate of decay. Alternatively, the surface may be coated with a catalyst. In the case of ozone as an active species, the high-temperature surface is preferably heatable to about 400° C. or higher.

[0014] The high-temperature surface is preferably placed inside the reactor downstream (with respect to the flow of gas) from the gas input and the substrate and upstream from the gas output. The high-temperature surface is preferably placed inside the reactor such that the temperature of the substrate is not substantially affected by the high-temperature surface. As the active species of a pre-cursor gas are purged, they are "de-activated" (i.e., destroyed) as they pass over the high-temperature surface.

[0015] Advantageously, more than one high-temperature surface may be placed inside the reactor according to the invention. In addition, the high-temperature surface or surfaces can be of various shapes. For example, the surface or surfaces may be a group of fins, a ring, a perforated plate, an ordered mesh of metal or other material, or a random mesh of metal or other material. The high-temperature surface is preferably shaped and situated inside the reactor such that the flow of gas through the reactor is not substantially impeded.

[0016] Advantageously, thin films may be grown on multiple substrates simultaneously according to the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[0017] The above and other objects and advantages of the invention will be apparent upon consideration of the following detailed description, taken in conjunction with the accompanying drawings, in which like reference characters refer to like parts throughout, and in which:

[0018] **FIG. 1** illustrates a cross-section of a known reactor used in atomic layer deposition;

[0019] **FIG. 1A** illustrates a plan view of a heater support used in the reactor of **FIG. 1** taken through line **1A-1A** of **FIG. 1**;

[0020] **FIG. 2** illustrates a cross-section of a reactor with a first embodiment of a high-temperature surface therein according to the invention;

[0021] **FIG. 2A** illustrates a plan view of the high-temperature surface of **FIG. 2** taken through line **2A-2A** of **FIG. 2**;

[0022] **FIG. 3** illustrates a cross-section of a reactor with a second embodiment of a high-temperature surface therein according to the invention;

[0023] **FIG. 3A** illustrates a plan view of the high-temperature surface of **FIG. 3** taken through line **3A-3A** of **FIG. 3**;

[0024] **FIG. 4** illustrates a cross-section of a reactor with a third embodiment of a high-temperature surface therein according to the invention;

[0025] **FIG. 4A** illustrates a plan view of the high-temperature surface of **FIG. 4** taken through line **4A-4A** of **FIG. 4**;

[0026] **FIG. 5** illustrates a cross-section of a reactor with a fourth embodiment of a high-temperature surface therein according to the invention;

[0027] **FIG. 5A** illustrates a plan view of the high-temperature surface of **FIG. 5** taken through line **5A-5A** of **FIG. 5**;

[0028] **FIG. 6** illustrates a cross-section of a reactor with a fifth embodiment of a high-temperature surface therein according to the invention;

[0029] **FIG. 6A** illustrates a plan view of the high-temperature surface of **FIG. 6** taken through line **6A-6A** of **FIG. 6**;

[0030] **FIG. 7** illustrates a cross-section of a reactor with a sixth embodiment of a high-temperature surface therein according to the invention;

[0031] **FIG. 7A** illustrates a plan view of the high-temperature surface of **FIG. 7** taken through line **7A-7A** of **FIG. 7**;

[0032] **FIG. 8** illustrates a reactor with more than one gas input and gas output according to the invention;

[0033] **FIG. 9** illustrates a reactor with multiple substrates therein according to the invention;

[0034] **FIG. 10** illustrates another reactor with multiple substrates therein according to the invention;

[0035] **FIG. 11** illustrates a reactor in which the flow of gas is horizontal according to the invention;

[0036] **FIG. 12** illustrates another reactor in which the flow of gas is horizontal according to the invention; and

[0037] **FIG. 13** is a flow chart of a process for growing thin films according to the invention.

DETAILED DESCRIPTION OF THE INVENTION

[0038] Atomic layer deposition (ALD) processes are used to grow multi-layered thin films for use in a variety of semiconductor fabrication applications. Such applications include DRAMs, SiO_2 dielectrics, and gate dielectrics. In typical ALD processes, pre-cursor gases enter a reactor one at a time via one or more gas inputs. Pre-cursor gases used in ALD are often chosen for their self-regulation properties with respect to growth. In some ALD systems, one of the pre-cursors is or includes an active species. For example, in a system to grow aluminum oxide, pre-cursors of trimethylaluminum (TMA) and ozone (ozone includes O_3, O_2, and O^*) are alternately entered into a chamber. Ozone includes the active species O_3 and O^*.

[0039] When a pre-cursor gas reacts with a substrate inside the reactor, a portion of the pre-cursor gas saturates the substrate forming a monolayer of atoms on the substrate. After the pre-cursor gas reacts with the substrate, the pre-cursor and active species (if any) are purged out of the reactor. This is done by either pulling a vacuum on one or more gas outputs of the reactor, forcing an inert gas (e.g., argon) through the reactor, or both.

[0040] After the first monolayer is deposited and the first pre-cursor purged, a second pre-cursor gas enters the reactor. This second pre-cursor reacts with the deposited portion of the first pre-cursor gas (i.e., grows on top of the deposited portion of the first pre-cursor gas). The remaining pre-cursor gas and active species (if any) of the second pre-cursor gas are then purged from the reactor. This process is repeated until the film is grown to the desired thickness.

[0041] FIG. 1 illustrates a cross-section of a typical reactor for ALD. Gases enter reactor 100 via a gas input 120, which is coupled to a gas line 110. Gas line 110 may be connected to one or more gas sources (not shown). Gas selectively enters reactor 100 by opening or closing valves (not shown) in gas line 110. Gases exit reactor 100 via gas output 190.

[0042] Inside reactor 100 is one or more heaters 140. Heater 140 is supported by heater column 144 and heater support 146. Substrate 130 rests on and is substantially flush with surface 142 of heater 140. Surface 142 should be heated to a temperature suitable for the ALD of the film being grown. That is, surface 142 should be at a temperature that causes a pre-cursor gas to react with the substrate. Substrate 130 may rest on surface 142 simply due to gravity or be held under a vacuum or by mechanical means, or any combination thereof. The surface of substrate 130 with which the pre-cursor gases react does not have to face upward or towards the gas input (however, it should not face down on surface 142). Alternatively, substrate 130 can be placed near heater 140, instead of on it.

[0043] Surface 142 is preferably larger in both length and width than the largest substrate to be placed on surface 142. Surface 142 and heater column 144 are preferably cylindrical. This allows gas to pass over substrate 130 and through reactor 100 more rapidly as compared to surfaces and columns of other shapes. However, surface 142 and heater column 144 can still be of other shapes such as square, hexagonal, or octagonal.

[0044] FIG. 1A illustrates a plan view of heater support 146. At the center of support 146 is a base 150 on which column 144 rests. Extending radially outward from base 150 are several arms 152 that extend to ring 154. As shown, heater support 146 has several openings 156 to allow gas to pass through. Only one arm may be required to support base 150. Ring 154 may be connected to, or be a part of, reactor wall 102.

[0045] When growing ALD films, pre-cursor gases and their active species should be purged from the reactor as quickly as possible after the pre-cursor gases react with the substrate. When mass producing ALD films, purge time becomes an important factor in the number of films that can be produced in a given time.

[0046] Purging of active species may be difficult when they do not quickly decay into non-active species. This decreases the throughput of the reactor and the overall ALD process time. Non-active species are more readily purgeable because they are more stable and less reactive than active species.

[0047] To decrease the purge time of active species used in ALD, which are often temperature sensitive, a high-temperature surface is placed in the reactor in accordance with the invention. The high-temperature surface decreases the half-life of the active species and thus decreases purge time. For ALD reactions using, for example, trimethylaluminum (TMA) and ozone as the pre-cursor gases, the active species of ozone (O_3 and O*) usually limit how fast the ALD reactions can be completed. At 250° C. (and 1 Torr) the half-life of ozone is about 76 seconds. The half-life drops to about 0.75 seconds at 400° C. (and 1 Torr), and to about 0.02 seconds at 600° C. (and 1 Torr).

[0048] The high-temperature surface is preferably positioned inside the reactor such that the pre-cursor gases react with the substrate before coming in the vicinity of, or in contact with, the high-temperature surface. In other words, the high-temperature surface is preferably downstream from the heater surface and substrate and upstream from the gas output. As the active species of a pre-cursor gas are purged, they are de-activated or "destroyed" (i.e., their reactivity is destroyed) as they pass over the high-temperature surface.

[0049] FIG. 2 illustrates a cross-section of a reactor 200 with several high-temperature surfaces 280 therein according to the invention. High-temperature surfaces 280 are "fins" that protrude from inner wall 202 of reactor 200. Fins 280 may be made of any suitable material or materials that can be heated to a temperature high enough to destroy (i.e., induce the rapid decay of) the active species of pre-cursor gases used in ALD processes. Fins 280 also may include (e.g., be coated with) a material that catalyzes the destruction of the active species. For example, in the case of ozone, fins 280 may include MnO, MnO_2, or CuO. Arrows 201 illustrate the flow of gas through reactor 200.

[0050] FIG. 2A illustrates fins 280 extending radially outward from inner wall 202. Fins 280 are preferably not in contact with heater column 244 and may be any suitable shape that does not substantially impede gas flow. For example, the width (along the surface of wall 202) of fins 280 may be substantially smaller than their length (i.e., the portion that extends outward from wall 202). Fins 280 may also be arranged in any suitable way that does not substantially impede gas flow. For example, fins 280 may be pitched. In other words, fins 280 may be situated at angles similar to fan blades.

[0051] FIG. 3 illustrates a cross-section of a reactor 300 in accordance with the invention. Closely surrounding heater 340 and preferably slightly below heater surface 342 is heat ring 380. Ring 380 is made of a material or materials that can be heated to a temperature high enough to destroy the active species of pre-cursor gases used in ALD processes. Ring 380 can be, for example, ceramic or Inconel. Heat ring 380 preferably has a flat circular surface and may be supported and connected to reactor wall 302 by support 382.

[0052] FIG. 4 shows another embodiment of a high-temperature surface inside a reactor according to the invention. High-temperature surface 480 is a heated pumping ring with pumping ports (e.g., passageways or ducts). Pumping ring 480 is heated to a temperature high enough to destroy the active species of a pre-cursor gas used in ALD processes. Gases are pulled through openings 486 of pumping ports 484 located on top surface 488 of pumping ring 480. Top surface 488 is preferably even with or below surface 442 of heater 440. Pumping ring 480 may be similar to pumping rings available from Applied Materials, of Santa Clara, Calif. Barrier 490 preferably prevents gas from flowing past surface 442 to the output of reactor 400 without passing through openings 486 of pumping ring 480.

[0053] **FIG. 4A** shows openings **486** on top surface **488** of ring **480** to pumping ports **484** (not shown in **FIG. 4A**). Some of the gas entering reactor **400** is pulled through pumping ports **484** by a pressure differential. This pressure differential may be created by a vacuum or other type of pump (not shown) connected to pumping ports **484**. Pumping ring **480** may be connected to reactor wall **402** or supported by a support (not shown).

[0054] **FIG. 5** illustrates a reactor **500** with a high-temperature surface **580** according to the invention. Surface **580** is a perforated plate and preferably has a substantially circular opening in the middle of the plate with a diameter slightly larger than the diameter of heater column **544**. Surface **580** is preferably placed inside reactor **500** such that surface **580** and heater column **544** are not in contact. Surface **580** is heated to a temperature high enough to destroy the active species of a pre-cursor gas used in ALD processes.

[0055] **FIG. 5A** shows several openings **582** in surface **580**. Openings **582** may be small or large depending on the number of openings **582**. The size and number of openings **582** should be such that they do not substantially hinder gases from passing through reactor **500**, yet provide enough surface area of surface **580** to ensure that active species are destroyed. The outer diameter of surface **580** may be the same as the inner diameter of reactor wall **502**. Alternatively, the outer diameter of surface **580** may be less than the diameter of reactor wall **502** and may be supported by a support extending from wall **502** (not shown).

[0056] **FIG. 6** illustrates another high-temperature surface inside a reactor **600** in accordance with the invention. Surface **680** includes a preferably ordered mesh (better seen in **FIG. 6A**) of material or materials that can be heated to a temperature high enough to destroy the active species of pre-cursor gases used in ALD processes. Such materials may be, for example, ceramics or Inconel. As illustrated in **FIG. 6A**, exemplary mesh portions **682**, **684**, and **686** of surface **680** are ordered.

[0057] **FIG. 7** illustrates a high-temperature surface **780** similar to surface **680**. Surface **780** is also a mesh of a material or materials that can be heated to a temperature high enough to destroy the active species of pre-cursor gases used in ALD processes. However, as shown in **FIG. 7A**, mesh **780** is a random arrangement of metal, other material, or combination thereof. Exemplary mesh portions **784** and **786**, for example, are shown to be randomly arranged in mesh **780**.

[0058] The reactors of **FIGS. 1-7** are shown with one gas input and one gas output for illustrative purposes only. Other numbers of gas inputs and gas outputs may be used. Reactor **800** of **FIG. 8**, for example, has two gas inputs **820** and two gas outputs **890**. Gas may be selectively input into reactor **800** via gas inputs **820** by operating valves (not shown) that control the flow of gas through gas lines connected to gas inputs **820**. Gas exits reactor **800** via gas outputs **890**. Similarly, gas outputs **890** may be coupled to valves (not shown) that control the flow of gas through gas lines connected to gas outputs **890**. Preferably, gas lines connected to the gas outputs are connected to pumps (not shown) to increase the throughput of gas through reactor **800**. Inside reactor **800** is surface **880**. Surface **880** is heated to a temperature high enough to destroy the active species of pre-cursor gases used in ALD processes.

[0059] Furthermore, although the embodiments of **FIGS. 1-7** are shown with one heating surface and one substrate, again for illustrative purposes only, other numbers of heating surfaces and substrates may be used in accordance with the invention.

[0060] For example, **FIG. 9** illustrates a cross-section of reactor **900**. Reactor **900** has multiple heaters **940** that have multiple heating surfaces **942**. Heaters **940** may be supported by heater supports **946**, which are fixed to reactor wall **902**. Alternatively, heaters **940** may be supported in other suitable ways such that substrates **930** placed on respective heating surfaces **942** may have thin films grown on them. In addition, a vacuum may be used to hold substrates **930** to respective heating surfaces **942** during the ALD. The surface of a substrate **930** on which a film is to be grown does not have to be level and can be oriented in any direction (however, the surface of substrate **930** on which a film is to be grown should not face down on heater surface **942**).

[0061] Inside reactor **900** is high temperature surface **980**, which is a perforated plate with openings **982**. Surface **980** is heated to a temperature high enough to destroy the active species of pre-cursor gases used in ALD processes.

[0062] **FIG. 10** illustrates a cross-section of reactor **1000**. As shown, thin films may be grown on multiple substrates **1030**, which are each on or near a heater (not shown). After gas passes substrates **1030**, the gas passes over and through high-temperature surface **1080**, which can be any one of surfaces **280**, **380**, **480**, **580**, **680**, **780**, **880**, or **980**. The gas exits reactor **1000** on the same side as it enters reactor **1000**.

[0063] **FIG. 11** shows a cross-section of reactor **1100**, which is arranged such that the flow of gas from gas input **1120** to gas output **1190** is horizontal. The direction of gas flow is not important provided that the number of atoms deposited on a substrate is substantially uniform across the substrate and that the amount of atoms deposited on each subsequent monolayer is also substantially uniform.

[0064] Inside reactor **1100** are two substrates **1130** fixed to two respective heating surfaces **1140**. Substrates **1130** may be held to heaters **1140** by, for example, vacuum. The surface of each substrate **1130** on which a film is to be grown preferably faces the center of reactor **1100**. This ensures that substantially uniform monolayers of atoms are deposited on the substrate. A high-temperature surface **1180** is downstream (with respect to the flow of gas) from substrates **1130** and heaters **1140**. Surface **1180** is heated to a temperature high enough to destroy the active species of pre-cursor gases used in ALD processes.

[0065] **FIG. 12** illustrates a cross-section of reactor **1200** in which the flow of gas over substrate **1230** is again horizontal. High-temperature surfaces **1280** are downstream (with respect to the flow of gas) from substrate **1230**. Surfaces **1280** are heated to a temperature high enough to destroy the active species of pre-cursor gases used in ALD processes.

[0066] The reactors of the invention can be of any type suitable for ALD including depression reactors and barrel reactors.

[0067] High-temperature surfaces such as surfaces **280**, **380**, **480**, **580**, **680**, **780**, **980**, **1080**, **1180**, and **1280** may be

heated by, for example, an electrical power source external to the reactor in which the surface is located. High-temperature surfaces may also be heated by, for example, heat convection.

[**0068**] **FIG. 13** shows an ALD process in accordance with the invention. At **1302**, a pre-cursor gas enters a reactor. At **1304**, the active species of the pre-cursor gas react with a substrate resulting in a monolayer of atoms on the substrate. The active species are substantially de-activated at **1306** when they come in the vicinity of, or into contact with, one or more high-temperature surfaces, such as surface **280, 380, 480, 580, 680, 780, 980, 1080, 1180**, or **1280**, inside the reactor. The remaining gases are purged from the reactor at **1308**. If the desired thin film thickness has not yet been grown, then at **1310**, the process returns to **1302**.

[**0069**] The above embodiments destroy active species of pre-cursor gases insitu by subjecting them to a high-temperature surface in the same reactor in which the ALD process occurs. In those ALD processes in which active species of pre-cursor gases can be destroyed by subjecting them to a cold-temperature surface, a cold-temperature surface may be alternatively placed inside the reactor. The cold-temperature surface may be the same shape as any of high-temperature surfaces **280, 380, 480, 580, 680, 780, 980, 1080, 1180**, or **1280**. The cold-temperature surface can be at any temperature below the reaction temperature of the ALD process that induces rapid decay of active species. For example, the cold-temperature surface can be about 100° C., room temperature, freezing, or below freezing, depending on the active species to be destroyed.

[**0070**] Note that although semiconductor substrates have been described herein with respect to ALD, the invention is not limited to them. Other workpieces appropriate for ALD are also within the scope of the invention.

[**0071**] In addition, although the ALD processes described herein have been described using only two pre-cursor gases, the invention is not limited to two pre-cursor gases. For example, three or four pre-cursor gases may be used.

[**0072**] Thus it is seen that systems and methods of insitu post atomic layer deposition destruction of active species are provided. One skilled in the art will appreciate that the invention can be practiced by other than the described embodiments, which are presented for purposes of illustration and not of limitation, and the invention is limited only by the claims which follow.

We claim:

1. A reactor for use in atomic layer deposition, the reactor comprising:

at least one gas input through which gas enters the reactor;

a heater operative to heat a workpiece inside the reactor to a temperature suitable for atomic layer deposition;

at least one surface operative to be heated to a temperature high enough to substantially destroy that portion of a gas that does not react with the workpiece, the surface coated with a catalyst that increases the rate of destruction of the portion of the gas that does not react with the workpiece; and

at least one gas output through which gas exits the reactor.

2. The reactor of claim 1 wherein the surface is coated with MnO, MnO_2, or CuO.

3. The reactor of claim 1 wherein the surface is operative to be heated to a temperature greater than 200° C. and less than 300° C.

4. The reactor of claim 1 wherein the surface is operative to be heated to a temperature greater than 300° C. and less than 400° C.

5. The reactor of claim 1 wherein the surface is operative to be heated to a temperature greater than or equal to 400° C.

6. The reactor of claim 1 wherein the surface is selected from the group consisting of a ring, a mesh, a perforated plate, a fin, and any combination thereof.

7. The reactor of claim 6 wherein the ring includes ducts through which gas can flow.

8. The reactor of claim 7 wherein vacuum is pulled through at least one duct.

9. A reactor for use in atomic layer deposition, the reactor comprising:

at least one gas input through which a gas enters the reactor;

at least one gas output through which gas exits the reactor;

at least one heater operative to heat a semiconductor substrate inside the reactor to a first temperature; and

at least one structure operative to be heated to a second temperature wherein the structure is positioned inside the reactor between the heater and the gas output, and the structure is coated with a catalyst that increases the rate of destruction of that portion of a gas that does not react with the substrate.

10. The reactor of claim 9 wherein the first temperature is high enough such that the gas reacts with the substrate.

11. The reactor of claim 9 wherein the second temperature is high enough to destroy the portion of the gas that does not react with the substrate.

12. The reactor of claim 9 wherein the first temperature is lower than the second temperature.

13. Apparatus for use in atomic layer deposition, the apparatus comprising:

means for entering a gas into an enclosure;

means for causing a portion of the gas to react with a material in the enclosure;

means for heating the gas in the enclosure downstream from the material, the means for heating being coated with a catalyst that increases the rate of destruction of that portion of the gas that does not react with the material; and

means for purging the gas from the enclosure.

14. A reactor for use in atomic layer deposition, the reactor comprising:

an input through which a gas enters the reactor;

an output through which gas exits the reactor;

a heater operative to heat a workpiece to at least 200° C.; and

at least one structure operative to be heated to a temperature greater than 200° C. wherein the structure is positioned inside the reactor between the heater and the gas output, and the structure is coated with a catalyst that increases the rate of destruction of that portion of a gas that does not react with the workpiece.

* * * * *